Transient Analysis of Three-Phase Self Excited Induction Generator Using New Approach

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Abstract

In this paper, Matlab/Simulink based new saturation model is proposed to investigate the transient performance of a three-phase induction machine. The model as proposed is used to predict the transient performance of three-phase induction generator under different operating conditions. Closeness of simulated results with experimental results on a test machine proves the effectiveness of the proposed model.

Keywords

Modeling; Self Excited Induction Generator; Simulation; Transient Analysis

Introduction

Global environmental concerns and growing demand of isolated power plants are some of the major issues due to which self excited induction generators are getting more and more popular. Further operational and constructional advantages are some other factors which are responsible for rapid establishment of suitable self excited induction generators in contrast to conventional synchronous generators. Further in the absence of grid a wind turbine generator in self excited mode is found to be very useful for isolated and remote locations.

The self excited induction generator is essentially a three phase induction machine in which the magnetizing current is furnished by the static capacitors connected across the stator terminals [1, 2]. Whenever driven by a suitable prime-mover under favourable conditions, voltage build up occurs and power is transferred to connected load. The types of loads experienced on such isolated power plants consisting of self excited induction generators may be static/dynamic in nature. Sudden switching of such loads cause transients in the system, which are of immense interest. Therefore transient analysis of a machine is must for design consideration and some researchers tried to investigate the dynamic performance of such generators [3-8].

[9, 10] used the well tested d-q axis based conventional model to investigate the transient behaviour of three phase induction machine. [11-14] describes the basic concept of transient modeling of the machine.

Matlab / Simulink is found to be very useful tool for modeling electrical machine and it may be used to predict the dynamic behavior of the machines. In this paper Matlab / Simulink based new saturation model is proposed to study the dynamic behaviour of three phases self excited induction generator. Effects of 'capacitor switching', 'load variation', 'input variation' and 'variation in moment of inertia' on the transient performance of self excited induction generator have been taken in the present work.

Mathematical Modeling

The voltage equation of the induction machine model in rotor reference frame is given by [11-14];

$$[v_G] = [Z\ ]\,[i\ ] \tag{1}$$

where $[v_G]$ and $[i\ ]$ represents voltage and current matrices and are given as $\begin{bmatrix} v_{qs} & v_{ds} & v_{qr} & v_{dr} \end{bmatrix}^T$ and $\begin{bmatrix} i_{qs} & i_{ds} & i_{qr} & i_{dr} \end{bmatrix}^T$ respectively.

Impedance matrices as defined in equation (1) may be given as,

$$[Z] = \begin{bmatrix} R_s + L_s p & \omega_r L_s & L_m p & \omega_r L_m \\ -\omega_r L_s & R_s + L_s p & -\omega_r L_s p & L_m p \\ L_m p & 0 & R_r + L_r p & -0 \\ 0 & L_m p & 0 & R_r + L_r p \end{bmatrix}$$

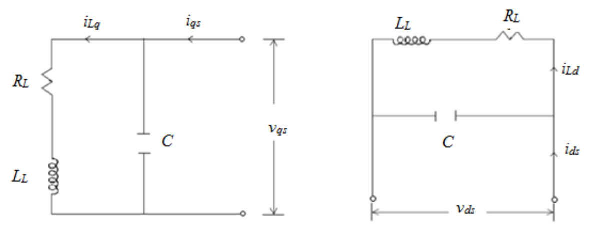

FIGURE 1 TWO-AXIS MODEL OF THREE-PHASE SELF EXCITED INDUCTION GENERATOR

And, the electromagnetic torque is

$$T_e = \frac{3}{2}\frac{P}{2} L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) \tag{2}$$

Equation of motion

Equation of motion used to relate the electromagnetic torque developed and load torque may be defined as;

$$T_e - T_L = (2J/P) p \omega_r \tag{3}$$

Capacitor side equations are

$$p[v_G] = (1/c)\,[i_c] \tag{4}$$

And $\quad [i_c] = [i] + [i_L] \quad$ (5)

$$[i_L] = [i_{Lq} i_{Ld}]^T$$

$$[i_c] = [i_{cq} i_{cd}]^T$$

Load side equation

$$[v_G] = L_L p[i_L] + R_L [i_L] \tag{6}$$

Saturation model

Saturation curve of the machine may be represented [14] in two ways as discussed below.

1) Conventional Saturation model

This curve is a graphical representation between rms values of air gap voltage and magnetization current. Therefore mathematically air gap voltage is a function of magnetizing current and is represented as:

$$E = f(I_m) \tag{7}$$

where

E = Per phase air gap voltage (rms).

I_m = Per phase magnetizing current (rms).

This curve for test machine [Appendix- A] may be used to develop the polynomial relationships between X_m and I_m [Table-1] and is used to account the saturation in the simulated model. This is the conventional way to account the effect of saturation in electrical machines and is generally adopted by most of the researchers [2, 15-17] for the transient and steady state analysis of induction machine.

2) Proposed Saturation model

This curve is a graphical representation between instantaneous values of air-gap flux linkage and magnetizing current. Therefore air-gap flux linkage is a function of magnetizing current and is represented as;

$$\psi = f(i_m) \tag{8}$$

where

ψ = Instantaneous value of flux linkage.

i_m = Instantaneous value of magnetizing current.

Such relationships have been used by [13, 14, and 17] in case of transformer and reactors. However none of the research persons used such representations for the analysis of induction generators. Conventional magnetization curve as shown in figure A.2 may be modified as in figures B.1 [Appendix-B], which show the variation of instantaneous values of flux linkages and magnetizing current. This is used to develop the relationship between x_m and i_m [Table-1]. For the first time, such relationship is proposed to account the saturation in three phase induction generator.

TABLE1 RELATION BETWEEN MAGNETIZING REACTANCE AND MAGNETIZING CURRENT

Relationship between magnetizing reactance and magnetizing current	
Due to conventional saturation curve	$X_m = 0.3372\, I^3_m - 1.8650 I^2_m + 9.1425\, I_m + 108.2482\Omega$
Due to proposed saturation curve	$x_m = 0.1205\, i^3_m - 0.7154 i^2_m + 8.6888\, i_m + 100.4563\Omega$

Results And Discussions

Figure 2 shows the MATLAB/SIMULINK based conventional and proposed models of a three-phase self excited induction generator used for simulations.

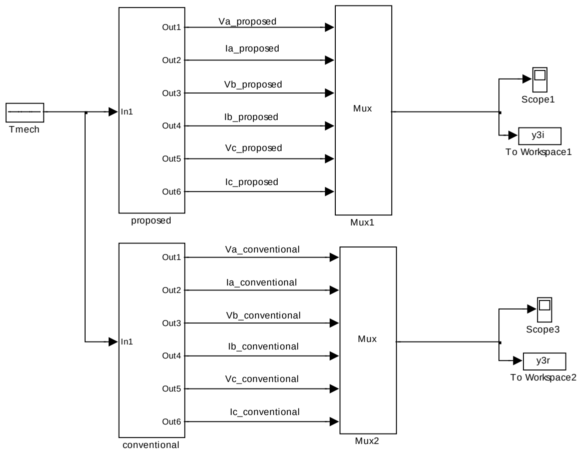

FIGURE 2 MATLAB/SIMULINK MODEL OF THREE-PHASE SELF EXCITED INDUCTION GENERATOR WITH PROPOSED AND CONVENTIONAL METHODOLOGY

Figure 3 shows the comparison of simulated and experimental results on test machine [Appendix-A]. Proposed saturation model yields better simulation results in contrast to conventional saturation model. This proves the effectiveness of proposed model in contrast to conventional model. Therefore it is recommended to use this model to predict the transient behavior of a self excited induction generator.

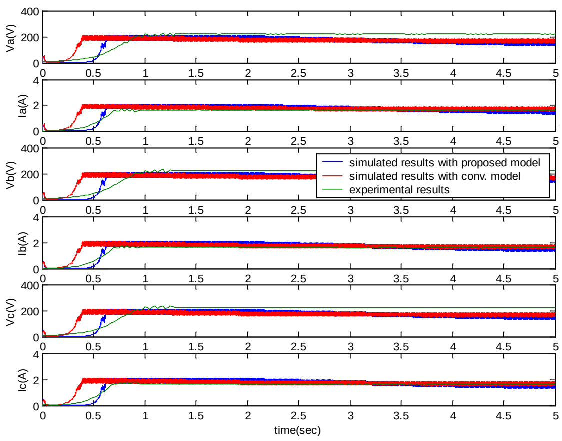

FIGURE 3 GENERATED VOLTAGES AND LOAD CURRENTS

Figure 4 to figure 7 show the comparison of simulated results with conventional and proposed modeling on test machine in self excited generating mode to analyze the effects of following:

- Capacitor switching
- Load switching
- Change in input power
- Change in moment of inertia

Capacitor switching

Figure 4 shows the effect of capacitor switching on the voltage build of induction generator under no load operation. The machine under consideration runs as a self excited induction generator with change of capacitance at 2, 3 and 4 seconds. At these instants capacitance is varied from 40 to 30, 30 to 20 and 20 to 10 microfarads respectively. From this figure following observations may be drawn:

- Proposed model results into high value of voltage in contrast to conventional model. In addition initial build up from zero to final value is dependent upon the type of modeling adopted for simulation.
- With decrease in capacitance the voltage decreased and ultimately it leads to voltage collapse, irrespective of the model used for simulation purpose.

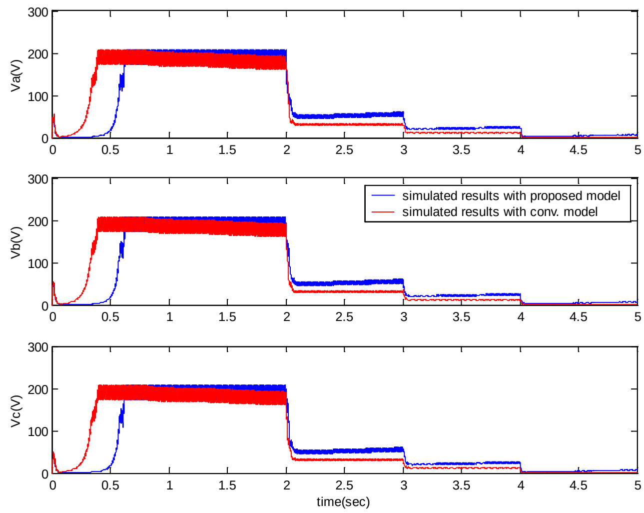

FIGURE 4 EFFECT OF CAPACITANCE SWITCHING UNDER NO LOAD OPERATION, SPEED=1500 RPM

Load switching

Figure 5 shows the effect of load switching on the transient behaviour of stator current of the test machine when load resistance is changed at 2 and 4 second. The load resistance is changed from 100 ohms to 200 ohms and 200 ohms to 400 ohms at the respective instants. Both models give the same transient response during the load switching. However initial response from zero value to final value of current found to be dependent upon the type of model used for simulation purpose.

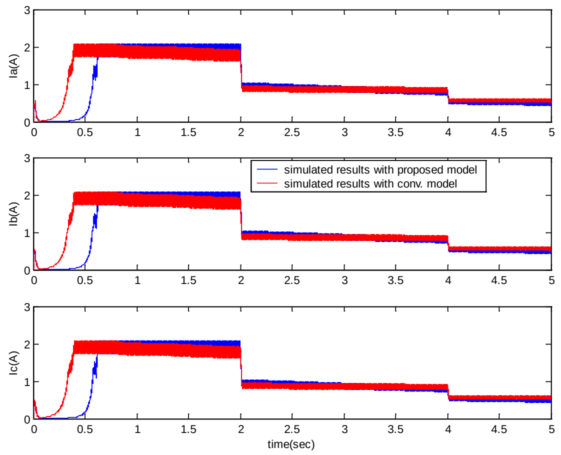

FIGURE 5 EFFECT OF LOAD SWITCHING, C = 40 MICROFARADS, SPEED = 1500 RPM

Change in input power

Figure 6 shows the effect of change of input mechanical power applied by the prime mover on the voltage build of induction generator. The machine under consideration runs as a self excited induction generator with change of input mechanical power at 1 and 3 seconds. At these instants input mechanical power is varied from 1 pu to 0.5 pu and 0.5 pu to 0.25 pu respectively. From this figure following observations may be drawn:

- With decrease in input power the voltage as well as the current is decreasing simultaneously.
- Initial build up from zero to final value is dependent upon the type of modeling adopted for simulation. Proposed model results into high value of voltage in contrast to conventional model.

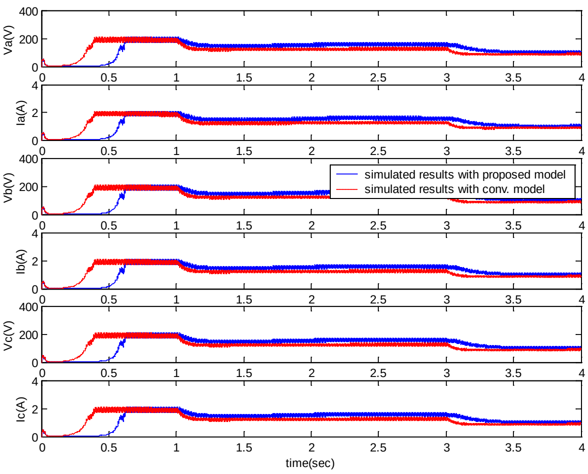

FIGURE 6EFFECT OF CHANGE IN INPUT POWER, C = 40 MICROFARADS, SPEED = 1500 RPM

Change in moment of inertia

It is well known that moment of inertia greatly affects the transient performance of three-phase induction machine in motoring mode. Figure 7.a to figure 7.c show the simulated results to look the effects of moment of inertia on the transient performance in self excited generating mode. It is observed that:

- Any change in the moment of inertia of the machine affects the voltage build up of generator, irrespective of the type of model adopted for analysis. However this effect is more pronounced in case of proposed model in contrast to conventional model.

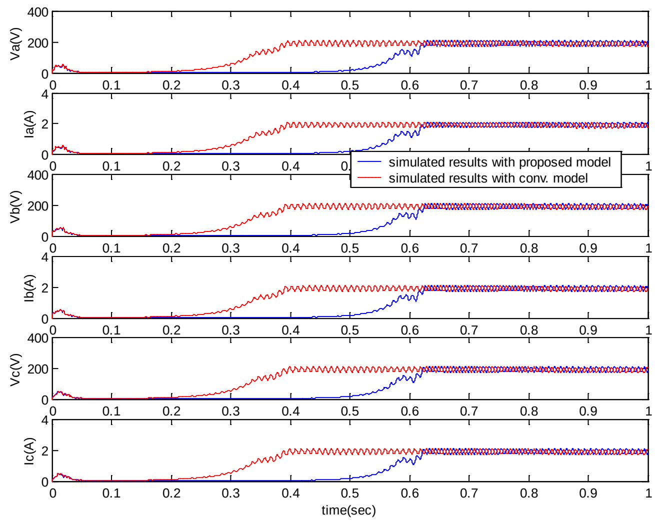

FIGURE 7 a EFFECT OF CHANGE IN MOMENT OF INERTIA, C = 40 MICROFARADS, SPEED = 1500 RPM WITH J = 0.913 KGM²

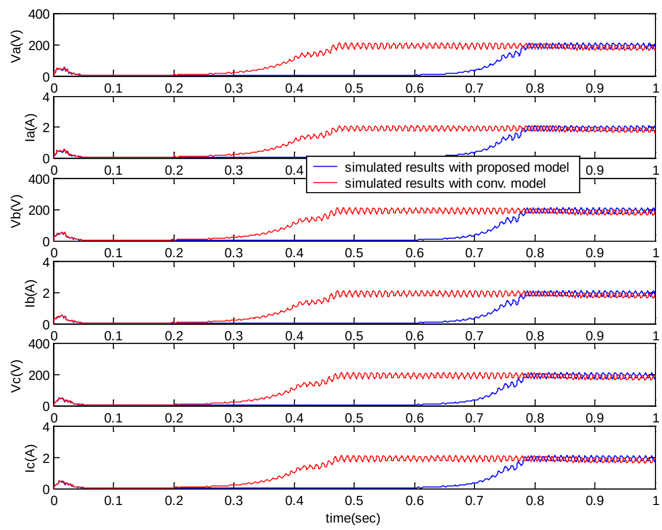

FIGURE 7 b EFFECT OF CHANGE IN MOMENT OF INERTIA, C = 40 MICROFARADS, SPEED = 1500 RPM WITH J = 0.95 KGM²

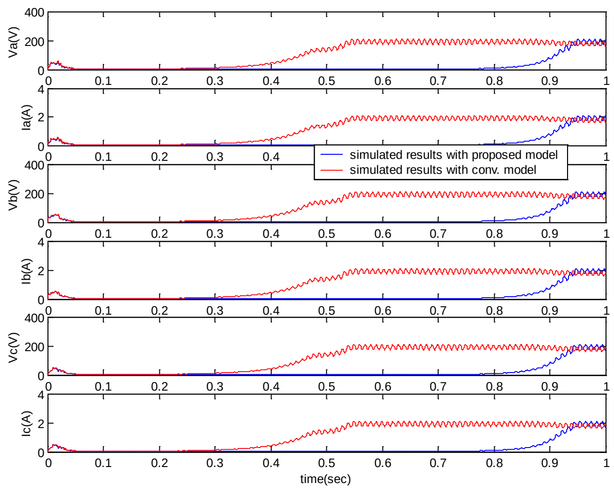

FIGURE-7 c EFFECT OF CHANGE IN MOMENT OF INERTIA, C = 40 MICROFARADS, SPEED = 1500 RPM WITH J = 1.0 KGM²

Conclusion

Due to global acceptability of self excited induction generators in wind power conversion, in this paper an attempt is made to analyze the transient behaviour of such machines under capacitor and load switching. In addition simulated results were also taken to include the effects of 'input mechanical power' and 'moment of inertia' on the performance of the machine. Matlab/Simulink based new model is proposed to investigate the transient performance of a self excited induction generator. Simulated results as obtained with new proposed model are found to be closer to experimental results. This proves the effectiveness and superiority of proposed model in contrast to conventional model. Simulated results as shown in figures 4 to figure 7 may be used to draw the following observations.

- Proposed model results into a delayed voltage build up in case of self excited mode for any given value of excitation capacitance, load, mechanical input and moment of inertia.
- Delay in voltage build-up further increases with an increase in moment of inertia i.e. especially for large rated machines.
- Nature of effects of 'capacitor switching', 'load variation', 'input variation' and 'variation in moment of inertia' is found to be same, irrespective of model used for simulation purpose. However simulated results (using proposed model) for such effects are found to be slightly different than those with conventional model.

From above observations it may be concluded that the proposed model, which is found to be superior to conventional model, results into different but reliable simulations. Therefore, it is strongly recommended to use this model for investigating the transient performance of self excited induction generator.

Appendix-A

3-hp, 3-phase, 50 Hz, 220 volts Induction Motor;

Stator Resistance, R_s= 3.35 ohms

Rotor Resistance, R_r = 1.7 ohms

Stator & Rotor Inductance,L_s =L_r = 15.44 mH

Moment of Inertia of test machine set up

With coupling,J = 0.913 kgm²

Two machines as shown in figure A.1 must run in the same direction in case fed individually. After that test machine is driven at synchronous speed with prime mover. Input current, power is recorded for different values of input voltage. Data as obtained is used to draw the magnetization curve of test machine as shown in figure A.2.

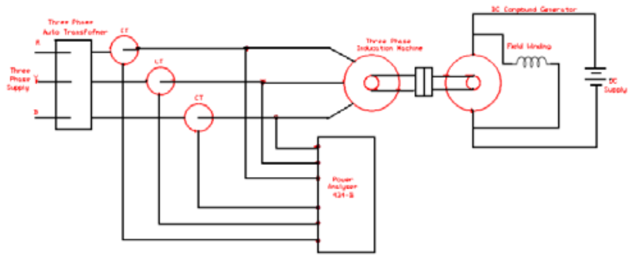

FIGURE A 1 SET UP FOR SYNCHRONOUS RUN TEST

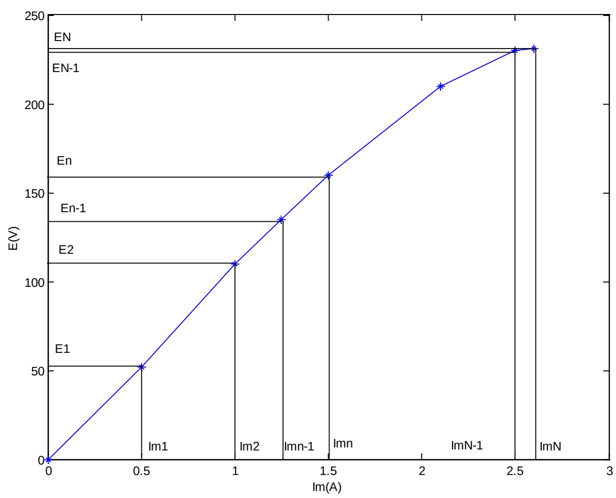

FIGURE A 2 CONVENTIONAL MAGNETIZATION CURVE

Appendix-B

Conventional magnetization curve as shown in figure A.2 may be converted to the proposed saturation curve with the procedure laid down by [13, 17] and it is shown in figure B.1:

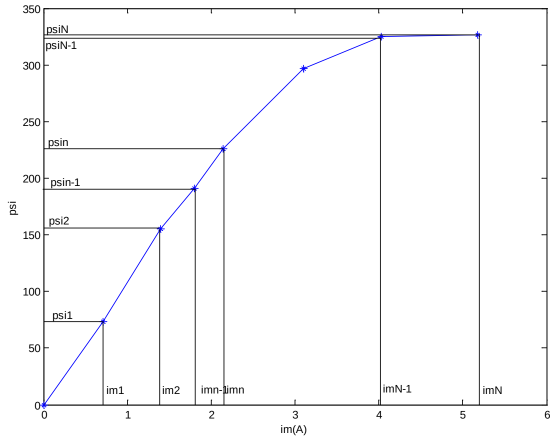

FIGURE B 1 PROPOSED SATURATION CURVE.

Conversion guidelines:

1. For a sinusoidal input voltage of frequency, ω, the corresponding flux linkage is given by

$$\Psi_k = \sqrt{2}E_k / \omega$$

k = 0, 1,-----n-1, n,-------, N

So, Ψ 0, Ψ 1, -----------, Ψ N can be obtained.

2. For calculation of proposed value of current i_m,

$$i_{mk} = \sum_{j=1}^{k} G_j (\Psi_j - \Psi_{j-1})$$

k = 1,-----n-1, n,-------, N

G_j is the slope of line joining points (j-1) and j, as seen from vertical axis [13, 17].

Nomenclature

R_s = Stator Phase Resistance/phase

L_s = Stator Self inductance/phase

L_m = Mutual inductance/phase

R_r = Rotor Phase Resistance/phase

L_r = Rotor self inductance/phase

ω_s =Angular speed (radian/sec.) in synchronously rotating reference frame

J = Inertia of Motor

T_e = Electrical Torque

T_L = Load Torque

p = Operator for differentiation

Subscripts:

q = Quadrature axis

d = Direct axis

s = Stator quantities

r = Rotor quantities

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